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THE FORM OF NANTASKET BEACH

DOUGLAS WILSON JOHNSON AND WILLIAM GARDNER REED, JR.

INTRODUCTION

This paper presents the results of a study of the form of Nantasket Beach, and includes a discussion of the stages of development through which the beach has passed to reach its present form, and of the processes by which that development has been accomplished. Our attention was directed to the Nantasket problem by Professor W. M. Davis, who was the first to discover the significance of the abandoned marine cliffs and beaches, and their relation to islands which have long since disappeared. Acknowledgments are also due the Boston street commissioners for assistance in securing old maps for examination; to Mr. E. G. Knight of Hull for information regarding conditions prior to the building of the County Road on Nantasket

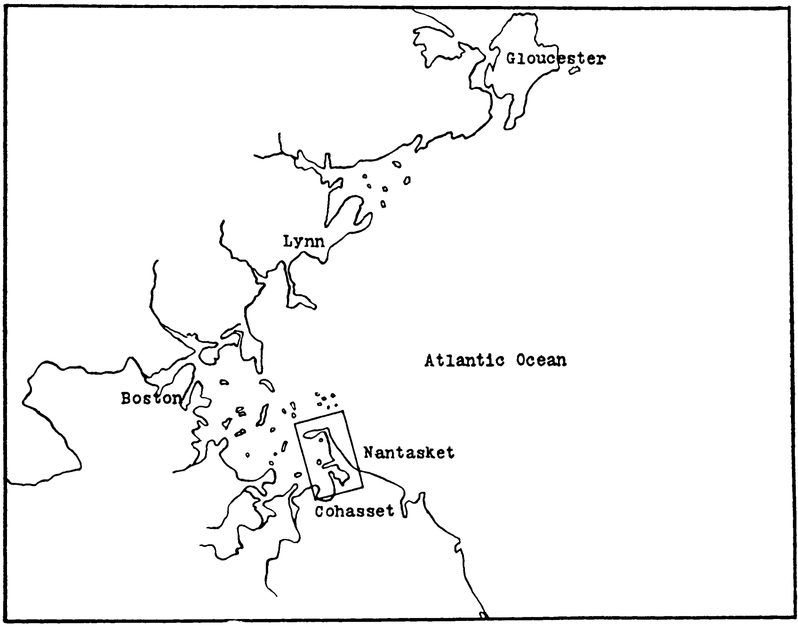

FIG. 1.—Location of Nantasket area.

Beach; and to Mr. F. M. Hersey of Boston, and the officials of the United States Coast and Geodetic Survey for numerous courtesies. In addition to these gentlemen, our thanks are due to many others in Boston and Hull for various services.

Nantasket Beach lies at the southeastern border of Boston Harbor, separating that portion of the harbor from the Atlantic Ocean (Fig. 1). The name "Nantasket Beach" is generally applied to all of that irregularly shaped lowland between the rocky hill of the Atlantic on the south, and the drumlin known as Allerton Great Hill on the north, and is not restricted to that portion of the lowland immediately bordering the ocean at the present time. As thus defined Nantasket Beach has a width of from a few hundred feet to more than half a mile, and a length of a little more than three miles. In our discussion we include the neighboring district of Hull, as well as several outlying islands, which are more or less closely related to certain phases of our investigation.

THE PROBLEM STATED

A casual study of the Nantasket district makes clear the fact that Nantasket Beach consists of sand, gravel, and cobbles, deposited by wave action between several drumlins which formerly existed as islands. The problem which we have to consider may therefore be described as a problem in island-tying by means of beaches. The tying of islands to each other and to the mainland, by the formation of connecting beaches, has been recognized as a common phenomenon along a youthful shoreline of depression, where islands are apt to be more or less numerous. Boston Harbor occurs on a shoreline of depression, but the islands which help to form the harbor, and which are frequently connected with each other and with the mainland by beaches, do not as a rule represent the summits of hills left as islands by the depression of a maturely dissected mainland. They are for the most part typical drumlins, the trend of whose long axes indicates that the ice-sheet which fashioned them moved from the land southeastward out to sea. It is evident that drumlin islands might be formed along a shoreline of elevation; hence the phenomena about to be described might occur along both of the standard types of shorelines. The principles involved in our discussion remain the same, whether the islands be composed of solid rock or unconsolidated glacial till; but it will appear that the stages of shoreline development are passed through more quickly, the wave-cut cliffs are more symmetrical, and the past conditions more easily reconstructed where drumlin islands are involved, as in the Nantasket case.

In the following pages we shall briefly review the principles of shoreline development, and then describe in some detail the present form of Nantasket Beach. On the basis of this description, and in view of the principles of shoreline development, we shall endeavor to reconstruct the initial form of the Nantasket district. Still guided by the principles of shoreline development, we shall next trace the successive steps in the development of Nantasket Beach from the initial form to the present form, with brief attention to the changes which will probably occur in the future. It will appear that Nantasket Beach is a very complicated example of island-tying, which illustrates in a remarkable manner the fact that shorelines are the product of systematic evolution according to definite physiographic laws.

LITERATURE

So far as we are aware, no detailed account of the physiography of Nantasket has been published. Professor W. O. Crosby (1893) has described the hard rock geology of the district just south of the beach in great detail and has considered the beach and drumlins at some length. He has also discussed the evidence of post-glacial changes of level in the Nantasket area. Other references to the district here described are found throughout the literature on the Boston Basin, but are not of importance in the present discussion.

In 1896 Professor W. M. Davis published a paper entitled "The Outline of Cape Cod," in which he discussed at some length the principles of wave and current action, and applied these principles in a study of the present form of Cape Cod and the past changes in the outline of the cape. The principles set forth in Professor Davis' essay are considered more fully on a later page.

Dr. F. P. Gulliver in a paper on "Shoreline Topography" (1899) has discussed at length various shore forms, including beaches which connect islands with the mainland or with each other. To such beaches he has applied the name "tombolo." Several types of tombolos are described, and Nantasket Beach, which might be described as a complex tombolo, is briefly mentioned.

In common with all students of shoreline topography, we are indebted to Dr. G. K. Gilbert's classic studies of lake shores for the elucidation of many of the principles upon which all shoreline studies must be based.

A brief note on "The Geology of the Nantasket Area," containing an outline of the physiography of the district, was published by Professor D. W. Johnson in *Science* three years ago.

THE PRINCIPLES OF SHORELINE DEVELOPMENT

Physiographers recognize two distinct classes of shorelines—those formed by a (relative) elevation of the land, called shorelines of elevation; and those formed by a (relative) depression of the land, called shorelines of depression. It is not necessary to repeat the characteristic features of these two classes of shorelines, nor to trace the successive stages by which young shorelines of each class acquire, by the time they reach maturity, curves of a relatively simple pattern, marine cliffs more or less bold, and shelving beaches at the foot of the cliffs. Initial characteristics and stages of development are both set forth in our best textbooks on physiography.

We may note, however, that the processes of shoreline development involve both wave and current action. It has been shown that wave action is largely confined to the erosion of the land margins, to the transportation of the eroded material a short distance from the shoreline, and to the deposition of the material in the deeper water; and to the heaping-up of sand, gravel, and cobbles into long ridges or beaches, where the conditions favor wave building more than wave erosion. Current action, on the other hand, effects but little erosion, and is mainly effective in the 'longshore transportation of material previously eroded by the waves or brought in by rivers. It has been shown that the combined effects of these two processes is to produce, in time, a shoreline characterized by long, simple curves, and free from sharp angles or other irregularities. Headlands are cut back, or retrograded, and re-entrants are built forward, or prograded, in the attempt made by waves and currents to straighten out the initial irregularities of the shores, and thus to establish a graded shoreline. The process is analogous to the formation of graded stream profiles by the degrading of elevations and the aggrading of depressions. If the waves cut back faster on one side of a headland than they do at the headland or beyond, and a strong current sweeps along the shore, the formation of a sharp angle at the headland is prevented by the prograding of the shore beyond the headland as rapidly as it is retrograded in the region of pronounced cutting. Thus, in the case of Cape Cod, Professor Davis has shown that the retrograding of the shore in the vicinity of Highland Light, due to active wave erosion, has been accompanied by a prograding of the shore farther north, where successive beaches have been built forward to maintain the simple curvature of a maturely graded shoreline. Equilibrium is reached, or the beach is maturely graded, when a gently curved or straight shoreline is developed; thereafter the headlands and beaches both retrograde gradually under the continued attack of the waves.

Inasmuch as the Nantasket problem involves a complex example of island-tying, we may here consider certain principles underlying the formation of connecting beaches, or tying bars as they are often called. If an island faces a large expanse of open water on which large waves are produced, and these waves come in general from one direction, the end of the island exposed to the brunt of the wave attack will be eroded, and the eroded material will be gradually drifted back along the sides of the island and strung out behind as a spit. In course of time the spit may reach the mainland or another island, and the island-tying is complete. Variations in local conditions may result in various forms of the tying bar; examples of several forms are described by Dr. Gulliver. It is possible that in some cases the bar may be built from the mainland out to the island (Gulliver, p. 192).

Backward tying is not the only form of island-tying to be observed along the shores. Lateral tying is certainly strongly developed in the Boston region, and we believe that many cases now regarded as examples of simple backward tying will prove to be more or less complicated examples of lateral tying. If wave erosion is most active on the eastern end of an island which lies at the mouth of a bay, and which is between two headlands situated to the north and south of the island (Fig. 2), several types of tying may result under different conditions. If there is no pronounced current action except the on-shore and off-shore tidal currents and the movements of the water due to waves coming from the east, simple backward tying may result (*a*). Under the same conditions as those just outlined, provided that the shallowing of the water inland is favorable, the material eroded from the head of the island may be drifted backward but at the same time northward and southward in curving lines along a zone where the water is of such depth as to favor deposition before reaching the bay head. Similar deposits from the headlands would meet those from the island, and lateral tying by curved bars would result (*b*). These bars might then be prograded, as explained on a previous page, until they formed a nearly straight shoreline between the island and the headlands. If the tidal action were fairly strong, the bars from the island and headlands might not join, leaving each portion as a spit, possibly more or less irregular in form, at its free end (*c*). If a pronounced 'longshore current existed, the waves still coming from the east, the material eroded from the island by wave action might be transported by the current from the island toward the headland, building a bar which would eventually tie the island to the mainland (*d*). In a similar manner a bar built northward from the southern headland might effect the tying of the island to the mainland (*e*). A sufficiently strong tide might prevent the tying in either case by maintaining a tidal inlet. But if the tying were effected,

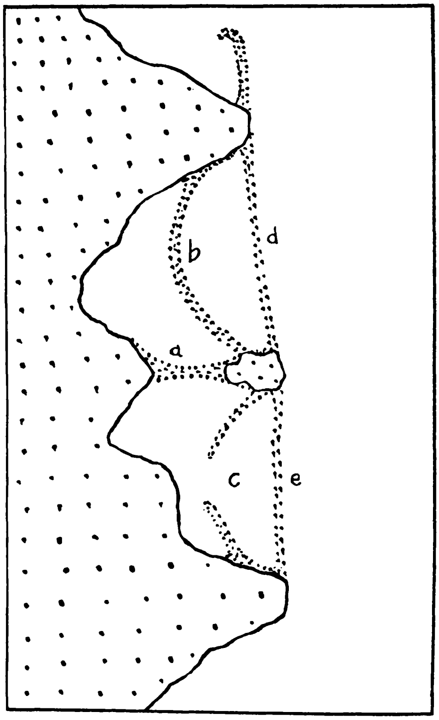

FIG. 2

it should be regarded as lateral tying, the connecting bar being built at right angles to the direction of wave attack, and parallel to the shoreline. Lateral tying similar to that represented by *d* and *e*, Fig. 2, might be produced if the character of the sea bottom caused the waves to break along the line *de* instead of entering the bay to the points *b* and *c;* also in case a barrier beach migrating toward the shore encountered the island and headlands in its progress.

If several islands instead of one were involved in the foregoing cases, more complex types of backward and lateral tying would result. Nantasket Beach represents a complicated case of both lateral and backward tying, involving for the most part prograded lateral tying bars of the types *b* and *c*, Fig. 2.

THE PRESENT FORM OF NANTASKET BEACH

The principal topographic features of Nantasket Beach are shown on the accompanying map (Fig. 8) based on a chart of Boston Harbor prepared by the United States Coast and Geodetic Survey (No. 246, C. & G. S. Boston Harbor, 1907). The larger features appear on the chart, but we have added the details of smaller beaches, wave-cut cliffs, etc. The irregular hills in the southern part of the map are composed of much altered sedimentary and igneous rocks which are very resistant and yield but slowly to the attack of the waves and weather. All other elevations on the map represented by contours are drumlins more or less eroded by wave action. The lower areas, including the lower ridges indicated by short hachures, are practically all of beach material; the exceptions consist of low areas of till between certain drumlins located close to each other, beach sand gathered into small dunes by the wind, and some deposits in swampy areas to be considered later. If we except the rock above mentioned, we may properly say that the features of the Nantasket region are due to marine action upon drumlins; for the effects of stream action and wind action are so slight as to be negligible.

The drumlins.—In describing the present form of the Nantasket drumlins it will be convenient to consider them in the order of their preservation from marine erosion. The letters in parentheses refer to the respective drumlins on the map, Fig. 8. The best preserved of the Nantasket drumlins is a small one called Hampton Hill (H), located in the southern part of the region, back of the beach. It has been slightly cliffed by the harbor waves, on the southwest, but is otherwise practically in the same condition as when the ice left it. Nantasket Hill (N) at Hull, also called Telegraph Hill, is another drumlin which has suffered but little erosion; it is slightly cliffed on the south. Thornbush Hill (T), just west of Nantasket Hill, is somewhat more strongly cliffed, but retains its initial form to a marked degree. The erosion has taken place at the southwest side. Sagamore Head (Sa), near Hampton Hill, preserves a nearly perfect outline except for a pronounced cliff on the the northeast side and a minor cliff on the north and west. The main cliff is well back from the present shoreline, and has evidently not been touched by the waves for many years.

North of Sagamore Head is White Head (W), a drumlin which retains its initial form fairly well on the south, although a slight cliffing is noticeable there; but which has a remarkable strongly curved cliff cut into its northern side (Fig. 11), and smaller cliffs on the northeast and east. Like the northeast cliff on Sagamore Head, the cliffs on the north and east sides of White Head are well back from the present shoreline and have long remained untouched by the waves. West of White Head are several low drumloidal hills, connected by lower areas of till and cliffed on both the north and south sides. Great Hill (G), at Allerton, has a strongly marked cliff on the eastern end where the waves are still cutting into the hill, although not so effectively as formerly. There has apparently been a slight cliffing on the western end of Great Hill, also. Strawberry Hill (St), about half-way between Allerton and Sagamore Head, is in many respects the most remarkable drumlin in the district. Except for a short distance along the northwest side, it has been cliffed throughout its entire circumference; a rather inconspicuous cliff is developed along the north side, more prominent cliffs on the south and west sides, while the southeast face is a splendid marine cliff long ago abandoned by the waves (Fig. 3). In fact the only point where the sea still reaches the drumlin is along its southwest side. There is a marked escarpment on the northeast corner of the cliffed drumlin, but much of this is due to the removal of till for road-building. Professor Isaiah Bowman informs us, however, that a small nip existed there before the excavations by man obscured the relations. It should be noted that the abandoned cliffs of Sagamore Head, White Head, and Strawberry Hill do not face in the direction of the present shoreline, but make pronounced angles with that shoreline, as shown by the map.

Quarter Ledge (Q) at Hull is a more than half-consumed drumlin, the marine cliff facing northward. Little Hill (L) at Allerton is of special interest because it is evidently but a small remnant of a drumlin (Fig. 10) on the northeast of Great Hill. It would doubtless have been completely removed by the waves ere this but for the protection afforded by a stone sea-wall constructed north and east of it to prevent its complete destruction. Skull Head (Sk) represents the final stage in the series, having been completely destroyed. This drumlin was situated to the northwest of Strawberry Hill, and so far as we can tell was probably of small size. It was apparently nearly destroyed by wave action from the west, the last remnant being removed by man and used as road material. Those who remember this drumlin remnant agree in describing it as having a gentle slope toward the east and a steep cliff facing west. The presence of great

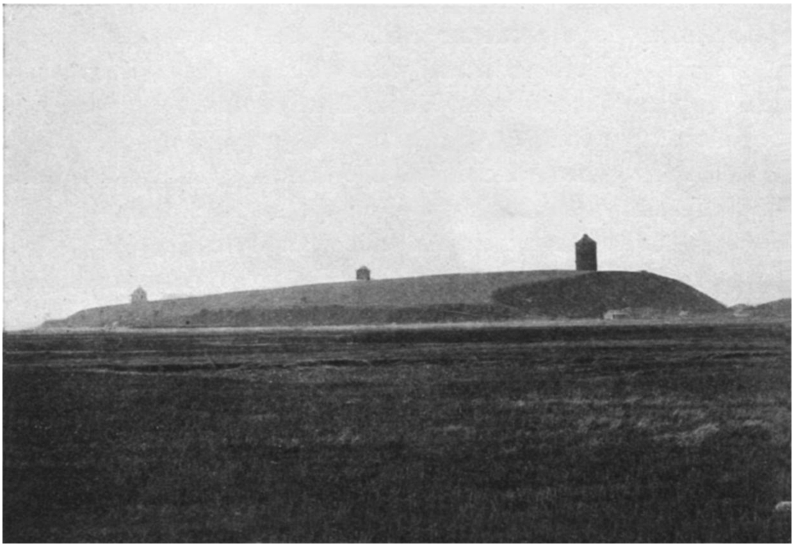

FIG. 3.—Strawberry Hill, from the south, showing abandoned marine cliffs; the higher cliff faces southeast.

bowlders near the supposed former site of this drumlin, the shape of the associated beaches, and the westward protuberance of the shoreline northwest of Strawberry Hill confirm the descriptions and location of the drumlin given by the inhabitants.

West of Nantasket Beach there are many drumlins more or less cliffed by marine erosion. On Nantasket Beach are drumlins in all stages of marine erosion, from slight cliffing to almost complete destruction. East of Nantasket Beach no drumlins are encountered. The suggestion is very strong that the sudden cessation of drumlins to the east is due to the complete removal of formerly existing drumlins by marine erosion. As will appear later there is strong evidence in favor of this interpretation.

The beaches.—Under this head are described the various spits, connecting bars, beaches, etc., both ancient and recent, which make up the composite feature called Nantasket Beach.

The beaches at Hull present no striking characteristics. The cliffed drumlins of Nantasket Hill, Thornbush Hill, and Quarter Ledge are close together, connected by lowland areas of till, and the cliffed portions are bordered by a narrow, sometimes bowldery beach. A sand spit, called Windmill Point, is strung out toward the west, probably under the influence of tidal currents passing through Nantasket Roads. This group is connected with Allerton by a bar believed to be the result of simple backward tying from Great Hill and Little Hill. The appearance of a **Y** bar is due to a railroad embankment built across the end of the bay back of Great Hill in order that the track would not have to be placed in the very exposed position on the seaward side of the Allerton drumlins. The protuberance of beach material from the northwest side of Great Hill is explained later.

From Allerton Great Hill on the northwest to the rock hills of Cohasset on the southeast a relatively straight beach borders the present shoreline. Back of this modern beach one observes parallel ridges of sand, gravel, and cobbles, in all respects similar to the higher part of the present beach which is still being acted upon by the waves. Still farther back the ridges become less prominent, until in the central areas of the Nantasket lowland they are scarcely perceptible. Moreover, they are no longer parallel to the modern beach, but are strongly curved, concave toward the east. At the extreme west, however, these curved beaches become prominent features once more and are as high in places as the modern beach.

If we examine the older beaches more carefully, we note several significant points. Just south of Allerton Great Hill the high and prominent westernmost beach, which we may call West Beach, is intersected by the modern beach. West Beach does not touch Great Hill and from the curvature of the beach it seems hardly probable that it connected with the former seaward extension of Great Hill. At its southern end West Beach ties to the northwest side of Strawberry Hill, just in front of the only part of the hill which has no bordering marine cliff. From the western side of the beach projects the protuberance of the Skull Head area, which destroys the otherwise symmetrical curve given to this portion of the harbor shoreline. Of the beaches which intervene between West Beach and the modern beach, a few connect with Strawberry Hill, others curve eastward as if to connect with something formerly situated in front of Strawberry Hill, and still others pass in front of the hill to connect with White Head or Sagamore Head farther south; while at the north all converge toward the intersection of West Beach with the modern beach, merging with the former or being cut off by the latter. The waves from the harbor are now attacking West Beach north of Skull Head, giving it a steeper western face, cutting off part of the western convexity, and building a small subsidiary beach toward the north. This attack of the harbor waves upon a beach formerly constructed by the powerful Atlantic waves has become so effective that sea-walls have been built in places to prevent further destruction of the old beach.

South of Strawberry Hill the relations are much the same, except that the beaches are less distinct and less regular in outline. The equivalent of West Beach does not connect directly with Strawberry Hill, but is truncated by a more recent beach or spit which extends southward from the southwest end of the great cliff on Strawberry Hill. The older main beach curves rather strongly southwest, continues south and southeast in much broken and complicated ridges, and finally spreads out in a broad, indefinite plain of beach material near the western end of White Head. The most prominent beach in this vicinity is one which extends from the eastern point of Strawberry Hill to the eastern end of White Head, and on which the County Road is located for much of the distance between the two hills. Both east and west of the County Road Beach are some fairly well-marked beaches, more or less obscured by sand dunes, especially toward the east. Two of the older beaches between White Head and Sagamore Head are especially prominent, and are practically straight. Both north and south of Strawberry Hill the beaches in the central areas, midway between the drumlin hills, are often so low and indistinct as to be nearly or quite imperceptible. In places the detection of the beaches is made easier by a difference in the grass and other vegetation growing on the beach ridges and in the intervening depressions.

THE INITIAL FORM

In our attempt to reconstruct the initial form of Nantasket Beach, we have appealed to three sources for information: (1) Some of the older inhabitants who recall the appearance of the beach in earlier days; (2) Old maps and charts of the region; (3) The principles of shoreline development applied to the interpretation of the present forms.

Shoreline changes take place with comparative rapidity, and in some cases a man may live to see profound alterations in the outline of the coast on which he lives. Some residents of Nantasket speak of a time when the sea used to come in to the present location of the County Road. It must be remembered, however, that people are apt to be impressed by the unusual, and that some long-past transgression of exceptional storm waves far across the present beach may be responsible for the impression that the sea is now farther removed from the road than it was fifty years ago. As late as 1898, during the "Portland Storm," breakers crossed the railroad track, which is well back from the present beach. In regard to the former location and general appearance of the remnant of Skull Head drumlin, now completely lost, the descriptions of the older inhabitants agree fairly well, and are corroborated by the physiographic evidence.

The old maps and charts of the region afford some evidence as to the general outline of the beach in earlier years, but prove to be too inaccurate to justify any conclusions as to recent changes in outline. A chart prepared by the United States Coast and Geodetic Survey in

1846 differs in minor points from the more recent charts of the same area, and a comparison of the two might be expected to show changes in the shoreline since 1846. Indeed, such a comparison has been made in connection with a study of cliff retreat at Allerton Great Hill and an estimated retreat of about two feet a year has been inferred on the basis of the comparison. A careful study of the two charts in the light of the geological features of the region makes clear the fact that one or both of them are too inaccurate to warrant any conclusions as to changes in shoreline based on such evidence. For example, it appears from the charts that the shoreline along the southeastern corner of Allerton Great Hill is farther east today than it was in 1846. Now the shoreline at this point is formed by the cliffed face of the hill, and since this hill is a drumlin which could not have been built forward since the glacial epoch, the charts are manifestly not sufficiently accurate to be used in determining recent changes in shoreline. On the other hand, it should be noted that the chart of 1846 indicates a shoreline so nearly like the present shoreline as to warrant the conclusion that the sea has not been materially closer to the County Road in the last sixty years than it is today, except during unusual storms. Indeed, a chart of Boston Harbor published in the fourth part of *The English Pilot* in 1709, while not accurate in details, seems to show that no pronounced changes in the shoreline of Nantasket Beach have occurred in the last two hundred years.

The application of the principles of shoreline development to the interpretation of the present form of Nantasket Beach offers the only means of determining the initial form of the beach. We believe that by this means it is possible to determine with a fair degree of certainty the geography of the Nantasket region before the present beach came into existence. The problem involves the restoration of the lost drumlins of this portion of Boston Harbor.

There is little difficulty in the restoration of those drumlins which retain their initial form to a considerable degree. The existing drumlins of the Boston district are of the same general type, none of them resembling the greatly elongated type found in some parts of New York. It is possible, therefore, to complete the outlines of Thornbush Hill (T) and Nantasket Hill (N) at Hull, Great Hill (G), Strawberry Hill (St), White Head (W), Sagamore Head (Sa), and Hampton

Hill (H) without danger of appreciable error. This has been done in Fig. 4, the restored portions being indicated by broken lines. Where more than half of a drumlin has been destroyed, the restoration cannot be made with the same degree of certainty, and we recognize that the location and size of such drumlins cannot be determined with absolute precision. The margin of error is not so large as materially to affect our problem, and the restorations of Quarter Ledge drumlin (Q) and Allerton Little Hill (L) in Fig. 4 (restored portions in broken lines) are believed to be essentially correct. The position of Little Hill will account for the peculiar protuberance of beach material northwest of Great Hill, if we agree that a spit trailing back from Little Hill by the action of waves and currents through Nantasket Roads would have a form somewhat similar to that of Windmill Point (WP) in Fig. 8. The restoration of the drumlins which are wholly destroyed involves a larger chance of error, and each individual restoration of this kind must be carefully considered.

The first restoration of a drumlin now completely destroyed (complete restorations shown by dotted lines) is that of Allerton Lost Drumlin (AL). That this drumlin formerly existed is shown by the relations of West Beach. The beach does not connect with Great Hill at the present time, but is abruptly cut off by the present shoreline a short distance south of Great Hill. That this beach formerly continued toward the east seems clear. It is equally clear that the seaward continuation of the beach would not connect with the seaward continuation of Great Hill, unless we imagine the beach to have been bent sharply northward. This last assumption is contrary to what we should expect in a beach as well developed as West Beach, has no evidence to support it, and is one which we are not permitted to make arbitrarily. The precise location of the drumlin with which West Beach must have connected cannot be determined with certainty, nor can its size be inferred; but that it occupied some such position as is indicated in Fig. 4 there would seem to be little doubt. It is not permissible to consider West Beach connected with the eastward extension of Little Hill, for this would require a marked northward bend in the beach, or the reconstruction of Little Hill on too large a scale.

It will be convenient to consider the restoration of Skull Head drumlin (Sk) next, as certain features connected with it will aid us in other reconstructions. The location of this drumlin is made clear, as already noted by the peculiar protuberance back of West Beach northwest of Strawberry Hill, by the occurrence of large bowlders along the shoreline at this point, and by the historical evidence. That the drumlin was small is indicated by the fact that it has been completely removed, although in a relatively sheltered position, and by the further evidence that this removal was accomplished mainly by the harbor waves, it being stated by those who remember the drumlin that the eastern slope was not cliffed, while the western face was a distinct marine cliff. The last remnant of this drumlin was removed by man in recent years. The location and size of Skull Head drumlin are believed to be essentially correct.

An examination of the great southeast cliff on Strawberry Hill shows that the cliff was formed by waves coming from the southeast, and not from the northeast, the direction of the present wave attack. The fact that a sharp angle on the cliffed drumlin projects forward on that part of the hill which would be most exposed to the direct attack of the waves had no other drumlin existed in front of it to protect it, confirms the opinion that the restoration of a drumlin must be made in the vicinity of the shallow area off-shore known as Strawberry Ledge. This we have called the Strawberry Lost Drumlin (SL). As will appear later, the former presence of a drumlin at this point accounts for the northeastern angle (recently blunted by excavations for road material) of Strawberry Hill, the small amount of cliffing on the north side of the hill, the eastward curve of the beaches northeast of the hill, the direction of the splendid southeast cliff, and a certain feature of West Beach to be considered in the next paragraph. Whether the shallow area at Strawberry Ledge has any connection with the Strawberry Lost Drumlin we are unable to say, but that the drumlin must have been located near this spot seems clear.

As has already been noted, Skull Head drumlin (Sk) was apparently not cliffed on the east, or was so slightly cliffed as not to attract the attention of persons who did notice the cliffing on the west. Yet this drumlin must have occupied a position fairly well exposed to the waves of the Atlantic, unless some protection from those waves was afforded by drumlins or beaches farther east. It should be noted also that West Beach is unusually high and broad, the modern beach at the east alone showing the same strength of development. In order that the waves should build a beach so extensive and so well developed, they must either have acted on the ancient West Beach shoreline for a long period of time, or must have been rapidly supplied with an immense amount of material previously reduced to a condition ready for beach construction. That the waves did not act for a long period of time in the vicinity of the ancient West Beach shoreline is shown by the absence of any considerable cliffing on the east end of Skull Head drumlin and the north side of Strawberry Hill. It is evident, moreover, that the large amount of material in West Beach could not have been supplied by the cliffed portions of the existing drumlins in that vicinity so it must have come from drumlins long ago destroyed, or from the sea bottom. We believe that the most probable condition which will account for all the facts is the former existence of a beach or series of spits more or less completely closing the space of open water between Strawberry Lost Drumlin and Allerton Lost Drumlin, thus forming a barrier which protected Skull Head drumlin and Strawberry Hill from wave action. The construction of this barrier was probably facilitated by the existence of another drumlin in the vicinity of the shallow area east of Bayside, and we have called the restoration of this drumlin (Fig. 4) the Bayside Lost Drumlin (BL). As will appear in the next section, the present relation of beaches and cliffs strongly suggests that a drumlin located in the vicinity of the Bayside shallow maintained the barrier so long as any part of the drumlin remained; but that with the complete removal of the drumlin the barrier was broken through, the accumulated débris swept rapidly back to the present position of West Beach, still protecting the east end of Skull Head drumlin but exposing a large part of the north side of Strawberry Hill to the waves which formed the low cliff we observe today.

The highly peculiar character of the cliffing on the north and northeast sides of White Head drumlin can be explained only by the restoration of a drumlin northeast of White Head. This we have called the White Head Lost Drumlin (WL). Its precise location cannot be determined, but it must have been close enough to White Head to control the marked curvature of the White Head cliff and the

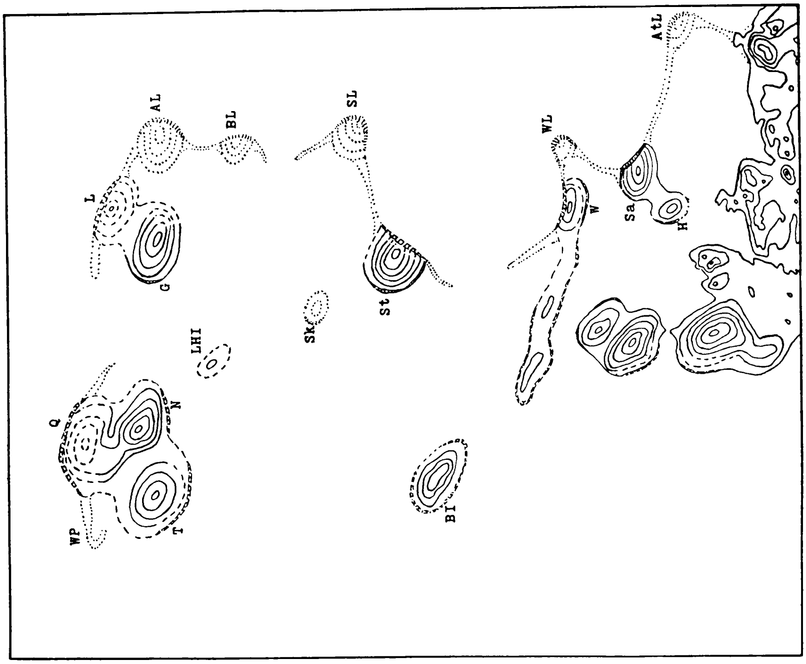
AtL
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Fig. 5

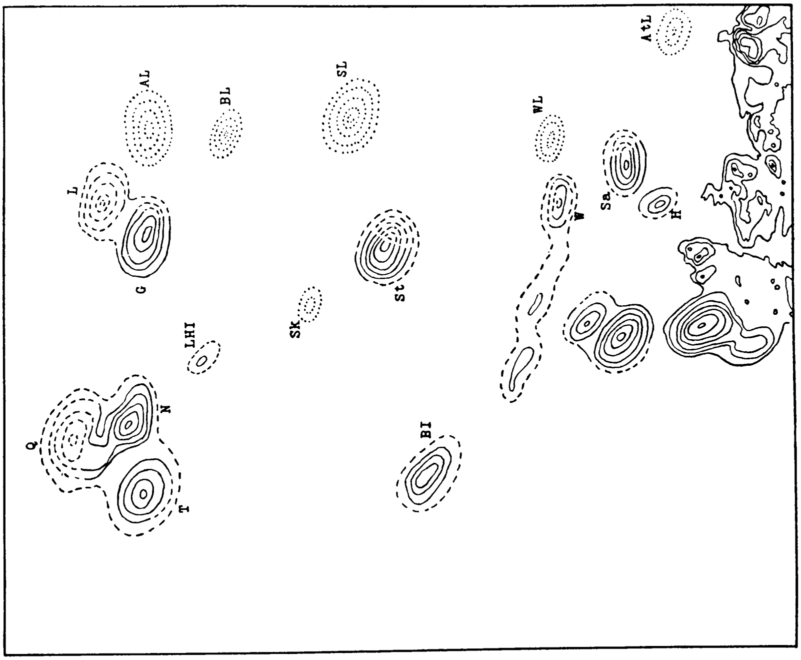
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Fig. 4

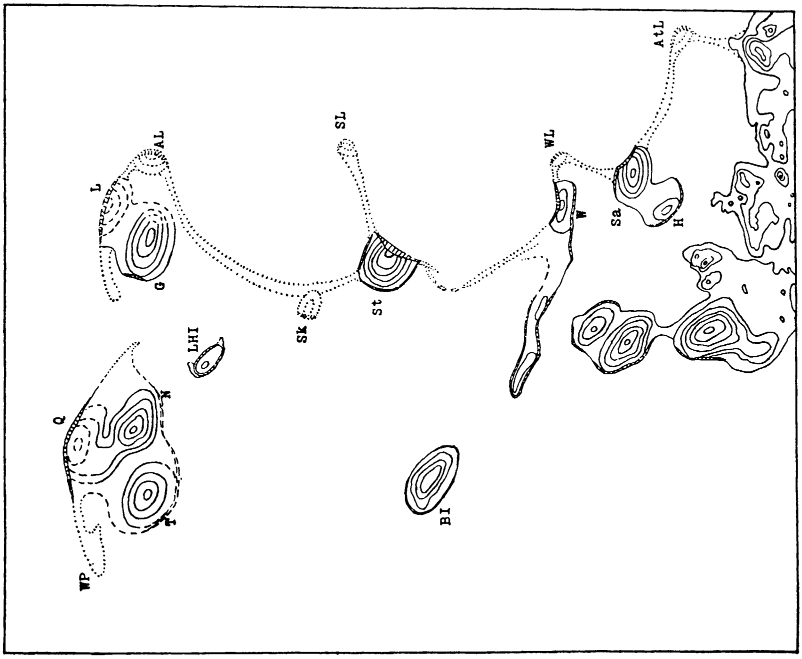

FIG. 6

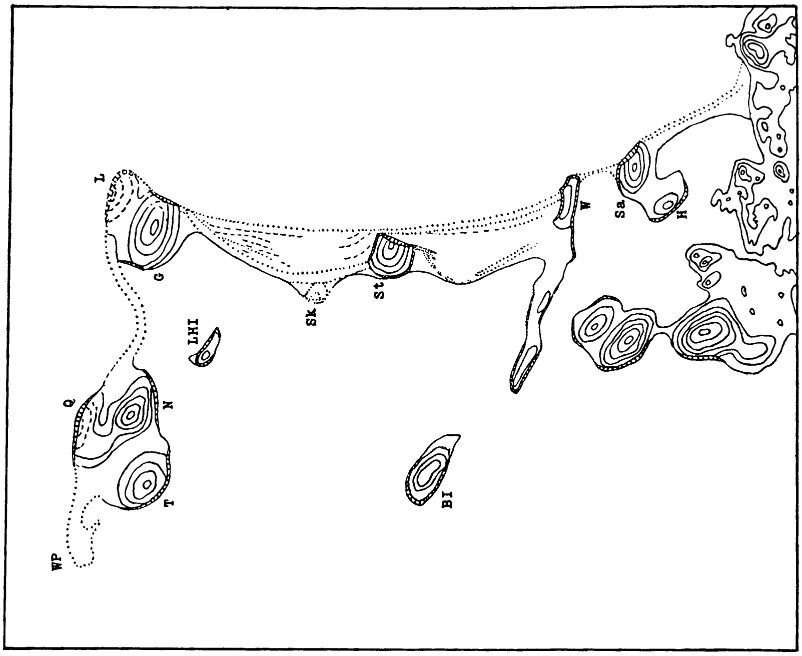

FIG. 7

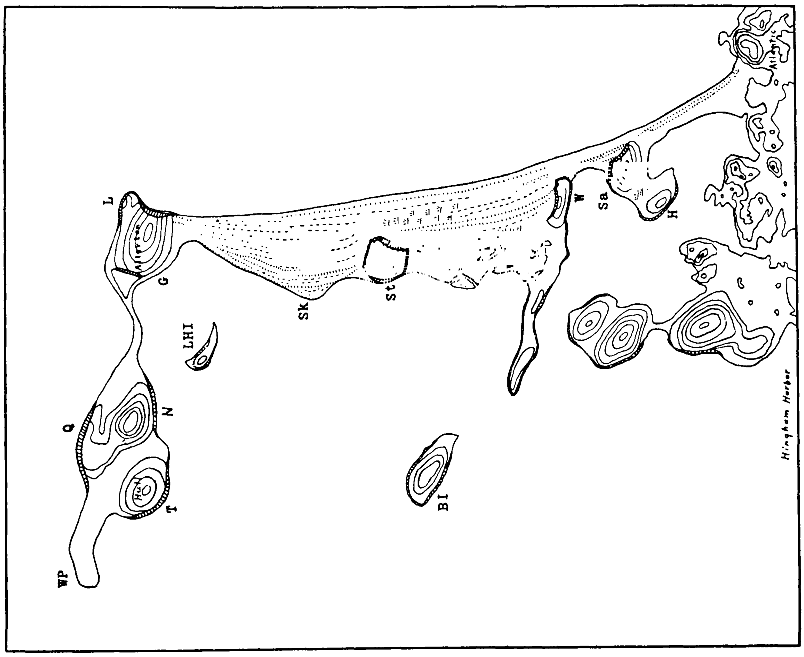

FIG. 8

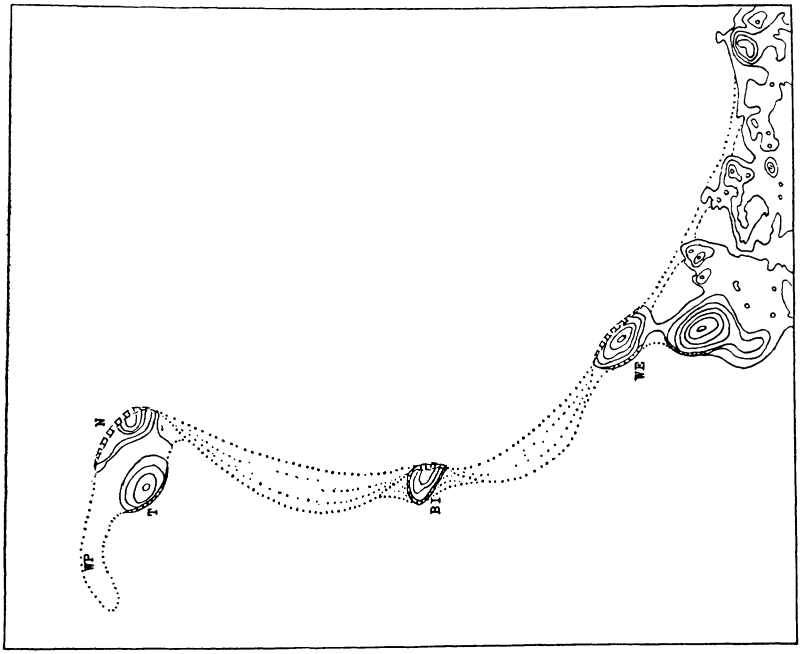

FIG. 9

less marked but distinctly curved cliff on the northeast side of Sagamore Head. The position assigned to it in Fig. 4 cannot be far from correct. The character of the Sagamore Head cliff, just referred to, necessitates the restoration of another drumlin to the southeast. Unless this drumlin existed somewhere in that region, affording protection to the southeast corner of Sagamore Head, it is difficult to understand why the latter was not cliffed directly from the east, and why the cliff is concave instead of convex. A shallow area north of Atlantic Head may have been the location of this drumlin as shown in Fig. 4. It is possible, however, that it may have been nearer Sagamore Head. We have called this restoration the Atlantic Lost Drumlin (At L).

This completes the restorations which seem required by the present forms of cliffs and beaches. That other drumlins may have existed in the region is, of course, possible; although the former existence of many more in the immediate vicinity of the Nantasket area would doubtless be indicated by peculiar alignments of cliffs on the remaining drumlins, or by the relations of the beaches. That additional drumlins may have existed still farther east is quite possible, but the data necessary for the reconstruction of such easternmost drumlins would be recorded only on drumlins and in beaches since completely destroyed. So far as the present problem is concerned the conditions shown in Fig. 4 may fairly be taken to represent the initial one of a series of developmental stages which we will now endeavor to follow until the present form of Nantasket Beach is reached.

THE DEVELOPMENT OF NANTASKET BEACH

In Fig. 5 we have endeavored to represent the conditions which probably existed in the Nantasket region at a much later stage than Fig. 4. The Allerton, Bayside, and Strawberry Lost drumlins have been much eroded by the waves and the material removed from them has been built into spits or connecting bars, which together with the remaining portions of the drumlins form a barrier to protect the east end of Skull Head drumlin and the north side of Strawberry Hill from any appreciable erosion. From Strawberry Lost Drumlin a bar ties backward to Strawberry Hill, protecting the northeast corner of the hill and helping to determine the direction of the wave attack which is producing the southeast-facing cliff. That Strawberry Hill and White Head were exposed to strong wave action while Skull Head and Great Hill were well protected is evident from the splendid development of the ancient marine cliff on the two former. White Head Lost Drumlin is much eroded, but still serves to determine the character of the cliff on the north side of White Head, and at the same time effectually to protect the eastern end of the same. Sagamore Head has been cliffed on the northeast, the character of the cliff being determined by the position of White Head Lost Drumlin and Atlantic Lost Drumlin, and the bars tying back from them. Atlantic Lost Drumlin is much eroded, and in addition to being connected with Sagamore Head has a short bar connecting with the rock cliffs just south.

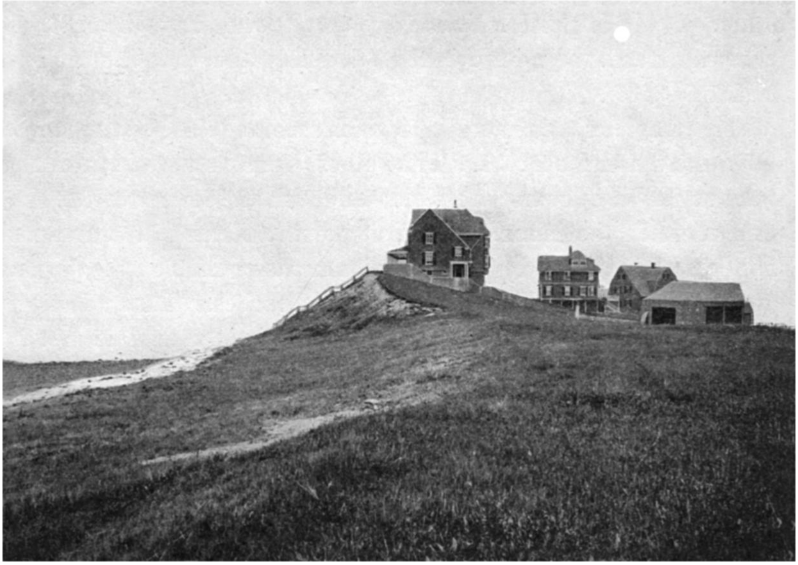

FIG. 10.—Little Hill, the remnant of an almost completely consumed drumlin.

Allerton Little Hill and Quarter Ledge drumlin, facing the main channel to the north, have been considerably eroded, while even the better-protected drumlins have, as a rule, been cliffed slightly, especially on their more exposed sides.

It is evident that some latitude is allowable in the restoration of certain of the features shown in the figure, without affecting the validity of the general interpretation here set forth. For example, the precise shape and location of the sand spits cannot be ascertained; and Atlantic Lost Drumlin might be nearer Sagamore Head, in which case the long bar connecting the two might be altogether absent, or represented by short spits or a short bar. We have indicated, however, those conditions which we consider most probable and the main features of the drawing are believed to be essentially correct.

Fig. 6 represents a later stage than Fig. 5. The complete destruction of Bayside Lost Drumlin has allowed the material formerly accumulated in its vicinity to be swept back to the Strawberry Hill–Skull Head region, and to be rapidly constructed into the prominent West Beach. At the north this beach still connects with the remaining portion of Allerton Lost Drumlin, thus accounting for the failure of this beach to touch Allerton Great Hill, a relation which is very distinct at the present time. At the south the connection with Strawberry Hill was far enough west to allow a slight cliffing along much of the north side of the hill. The absence of a pronounced cliff at the northeast corner of Strawberry Hill previous to recent excavations, and the eastward curve of some of the old beaches northeast of the hill (Fig. 3) indicate that a remnant of Strawberry Lost Drumlin still survived at the period represented by Fig. 6 and even later, preserving the backward-tying bar until West Beach was considerably prograded. Between Strawberry Hill and White Head spits or a curved bar nearly or quite close the space of open water, although the irregular character of the gravel ridges now observable at this point suggests that the bar may have been repeatedly broken through during heavy storms. The retreat of the shoreline on the southwest side of Strawberry Hill has caused the older beach ridge to be truncated by a sand spit now forming. Other minor developments are indicated, including the continued cliffing of various hills, and the growth of Windmill Point and other smaller spits.

In the stage represented by Fig. 7 the present characteristics of Nantasket Beach begin to be more easily recognizable. Allerton, Strawberry, White Head, and Atlantic Lost drumlins have all been completely removed. Prograding has gone on actively in the two re-entrant curves north and south of Strawberry Hill, the shorelines thus migrating eastward until a single beach describes a very gently concave curve from Allerton Little Hill to White Head. That the process of prograding was relatively rapid is indicated by the small size of the beaches in the inland areas north and south of Strawberry Hill. In places these beaches are almost imperceptible, and south of the hill it seems probable that the change in the position of the eastern shoreline from the westernmost beach to the County Road Beach was made without the formation of complete intermediate beaches. That the prograding had proceeded quite far, in the northern re-entrant at least, before the removal of the bar connecting Strawberry Hill with Strawberry Lost Drumlin, is shown by the development of faint beaches just north of the hill, curving eastward so strongly that they would pass in front of the restored portion of the hill if they were prolonged. These beaches must have been formed before the bar was destroyed. After the complete removal of Strawberry Lost Drumlin and the destruction of the bar, the ends of these beaches were eroded, as shown in Fig. 7, and the eastern angle of Strawberry Hill was slightly cliffed by the waves. In this manner the portion of the shoreline which had been prograded with reference to the Strawberry Lost Drumlin and bar, was retrograded until brought into harmony with the conditions existing after the destruction of drumlin and bar. Before the waves could seriously affect the the corner of Strawberry Hill the prograding of the entire beach (from Allerton Little Hill to White Head) as a single unit carried the shoreline eastward beyond the base of the hill. The prograding of the beach appears to have been connected with the retrograding of the headlands at Allerton and the removal of Whitehead and Atlantic Lost drumlins. As Allerton Lost Drumlin, Little Hill, and Great Hill have been cut back, the beaches to the south have been built forward, the point of no change, or fulcrum, being just south of the east end of Allerton Great Hill. The lack of a complete series of beaches south of Strawberry Hill may be connected with a more sudden westward migration of the southern end of the shoreline upon the disappearance of Whitehead and Atlantic Lost drumlins, and a consequent sudden eastward movement of the zone of wave building just north of Whitehead drumlin. As soon as the eastward migration of the beaches allowed the shoreline to clear the hill, the successive beaches appear to be more or less continuous from Allerton to Whitehead. The remaining changes indicated on the drawing need but little comment. The removal of White Head Lost Drumlin, together with the formation of the County Road Beach, has resulted in the cliffing of White Head on the east and northeast, while the removal of the Atlantic Lost Drumlin has allowed the connecting bars to swing back and form a single bar which unites with the rock cliffs at Atlantic Head.

The next stage in the development of Nantasket Beach is that of the present, represented in Fig. 8. The principal change from the preceding stage consists in the prograding of the beach until it makes an unbroken, gently curved shoreline from Great Hill to Atlantic Head; the further cliffing of White Head at the eastern end and the abandoning of the cliffs on White Head and Sagamore Head by the waves as the shoreline migrated eastward; the complete removal of the Skull Head drumlin, partly within recent years; the filling-in of the small bay on the south side of Windmill Point, largely within historic times; and further erosion of all the drumlins still exposed to wave action.

In Fig. 9 we have attempted to represent a possible future stage in the development of Nantasket Beach. At the present time the most effective wave erosion is concentrated upon Great Hill and the small remnant of Little Hill. But these hills control the future of the beach, the erosion of the rocky mainland at the southern end being so slow as to be practically negligible. Heretofore the retrograding of these hills has caused the prograding of the beach; at the present time, however, a condition of equilibrium prevails, and a further cutting-back of the hills must result in a cutting of the beach also. With Great Hill gone, the beach would connect Nantasket Hill, Little Hog Island, Strawberry Hill, White Head, and Sagamore Head. Strawberry Hill would be at an exposed angle of this beach and would soon be destroyed. Little Hog Island and White Head would be more exposed than before, providing the former had outlasted Strawberry Hill. Sagamore Head and Hampton Hill would take their turns in controlling the position of the beach until completely reduced by the wave attack. The drumloidal extensions west of White Head and the Hull district at the north will be the last remnants of Nantasket Beach to survive, and of these two the Hull district will probably last much longer. If this interpretation is essentially correct, the relations in the Nantasket region will, in the remote future, resemble those indicated in Fig. 9. It is possible that the connecting bars may be broken through by the sea in one or more places, and that sand spits may replace the bars here shown. This will depend on local conditions of water depth and other factors which cannot be predicted.

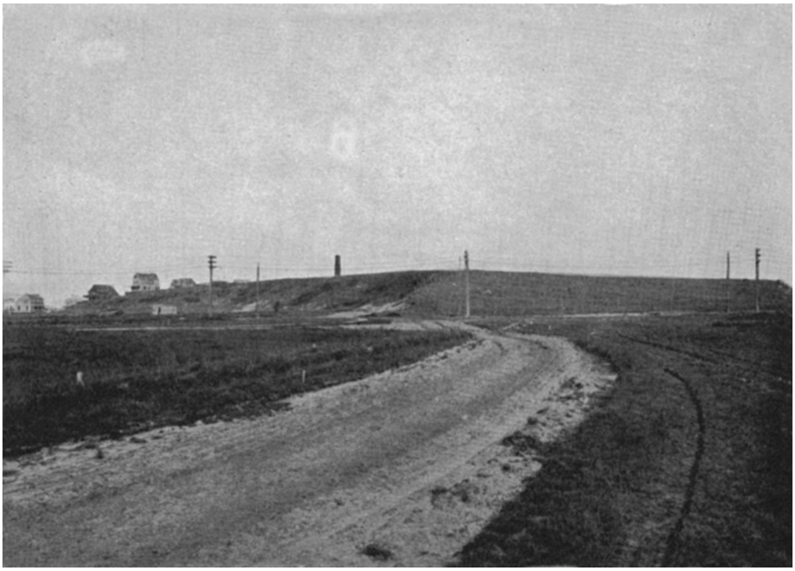

FIG. 11.—Whitehead Drumlin, showing concave marine cliff on north side.

At present the area here shown is shallow, and favors the building of bars as indicated.

The protection of Great Hill is the key to the preservation of the entire Nantasket Beach district. A sea-wall has been constructed for the preservation of Little Hill, and this, of course, means protection to the adjacent areas of Great Hill. By such protective measures man may indefinitely postpone the normal changes which Nature would effect in the Nantasket area. It is interesting to note that man has begun his work in controlling the development of Nantasket Beach just at the time the beach has reached the greatest size which Nature could probably give it. Heretofore the beach has been increasing in area. Hereafter the normal development of the beach, unless arrested, would result in decreasing its area.

CHANGES OF LEVEL IN THE NANTASKET AREA

Much has been written concerning possible elevations and depressions of the Massachusetts coast since the glacial epoch. The evidence is often unsatisfactory and contradictory, but is thought by many to indicate a gradual subsidence at the rate of approximately one foot in one hundred years. Professor Crosby believes that some of the drumlins, which now show no marked cliffs facing toward the Atlantic, were strongly cliffed before Nantasket Beach was completed, and that subsidence has carried these cliffs under water. "This view relieves us of the necessity of imagining a cordon of drumlins outside of the present beach which have been completely washed away, although it is not improbable that Harding's Ledge and the Black Rock Islets are the foundations of such vanished drumlins" (Crosby, p. 170). As we have shown above, there is abundant evidence that a number of drumlins did formerly exist outside of the present beach, and that these drumlins and their associated bars and spits effectively protected drumlins back of them from erosion. No subsidence is required to account for the lack of cliffing on the eastern ends of drumlins back of the present beach, and no evidence of submerged marine cliffs has ever been found.

It seems to us quite possible that there may have been a considerable depression in the Boston region since the glacial epoch; and that there may have been a very recent depression *of small amount* at the calculated rate of one foot in one hundred years. But that there has been any marked change in the relative position of land and sea during the last thousand years or more seems to us absolutely incompatible with the evidence furnished by Nantasket Beach. West Beach, as has already been pointed out, is similar in size and elevation to the beaches being formed along the present eastern shore of the Nantasket area. Had there been marked depression since the formation of West Beach, that beach would now be very low, possibly completely submerged. Had marked elevation occurred, West Beach should be relatively high, and other evidences of elevation should appear along the western margin of this beach. The close similarity between the oldest and latest beaches in the Nantasket area proves that the sea stood at about the same height when the two were formed. The intervening beaches are often low, because of the rapidity with which the shoreline was prograded for a time; but County Road Beach is strong and high, and may be compared with West Beach and the recent beaches.

The duration of this still-stand of the land may be roughly calculated. Judging from old maps, there has been no marked change in the width of Nantasket Beach during the last two hundred years. Judging from the rate of cliff cutting in various drumlins in the vicinity of Boston as determined by surveys extending over forty years or more, the length of time required for the removal of those portions of drumlins which have disappeared since the early cliffing of Strawberry Hill and Whitehead and the formation of West Beach, with liberal allowance for relatively rapid cutting of drumlins well exposed to the sea, could scarcely have been less than one thousand years, and was probably two or three thousand years. We conclude, therefore, that there have been no marked changes in the relative position of land and sea in the Nantasket area during the last thousand years at least.

CONCLUSION

The form of Nantasket Beach presents a variety of complicated phenomena which, when carefully studied, enable us to reconstruct with reasonable certainty the history of the development of the beach. It appears that the present form of the beach is not due to the accidental tying-together of a few islands without system, but represents one stage in a long series of evolutionary changes which have occurred in orderly sequence and in accordance with definite physiographic laws. Perhaps nowhere in the world can features of beach development be better studied than in the area here under investigation. Certainly nowhere in the literature is recorded an example of so complicated a shoreline preserving the records of its past development with such fidelity.

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